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A 25.5-Percent AMO Gallium Arsenide Grating Solar Cell

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SUMMARY

Recent calculations have shown that significant open circuit voltage gains are possible with a dot grating junction geometry. This paper investigates the feasibility of applying the dot geometry to the GaAs cell. This geometry is shown to result in voltages approaching 1.120 V and efficiencies well over 25 percent (AMO) if good collection efficiency can be maintained. The latter is shown to be possible if one chooses the proper base resistivity and cell thickness. The above advances in efficiency are shown to be possible in the P-base cell with only minor improvements in existing technology.

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INTRODUCTION

While under ideal conditions the GaAs solar cell should be able to operate at an AMO efficiency exceeding 27 percent, the best measured efficiencies to date barely exceed 19 percent. A recent analysis taking practical limitations into consideration has shown that both the N-base and the P-base GaAs cells in their planar configurations have the potential to operate at AMO efficiencies between 23 and 24 percent (ref. 1). For the former the enabling technology is essentially in hand, while for the latter the problem of passivating the emitter (N+) surface remains to be solved. The purpose of this paper is to describe a means of increasing P-base cell efficiency to the 25.5 percent level without having to passivate the emitter surface. As we will attempt to show, this can be accomplished through the use of a grating junction geometry.

THE GRATING CELL

A grating cell can be defined as a cell in which the junction (emitter) area has been reduced to a fraction of the total front (or rear) surface area. The purpose of going to a grating geometry is to secure an increase in voltage while maintaining (hopefully) a current level characteristic of a planar junction cell. The two simplest grating geometries are the stripe junction and the dot junction configurations. In the former the emitter is composed on an array of parallel stripes and in the latter it is composed of an array of equally spaced dots.

Although a previous theoretical analysis has indicated that the stripe grating geometry does not hold much promise for increased voltage (ref. 2), more recent calculations show that significant voltage gains are possible with the dot geometry (ref. 3). It has been shown that the effective base saturation current component of the dot grating cell decreases with the square root of the junction area. At the same time, because the emitter volume varies with the emitter area, the saturation current component from that region decreases linearly with junction area. A cell with a junction composed of an array of dots whose aggregate area is only 1 percent of the total cell area, for

instance, would have its emitter component reduced by a factor of 100 and its base component reduced by a factor of 10 as compared to a planar cell with the same total area. The dot grating geometry thus has the potential for producing significant increases in cell voltage.

This concept is especially intriguing in the case of the P-base cell with its unpassivated emitter surface. In this case, the reduction of the N-type emitter surface area by several orders of magnitude would result in a cell almost completely bounded by passivatable P-type surfaces. The need to passivate the remaining N-type areas would be obviated by virtue of the relatively small contribution these areas would make to cell performance. Thus in the P-base cell the dot grating geometry is not only capable of producing a large decrease in J_0, but it also would eliminate essentially all of the hard-to-passivate N-type surfaces. The latter improvement should enable the achievement of J_{sc} levels comparable to those that would be obtained if the emitter surface were in fact passivated. Using these concepts let us calculate the efficiency expected from a P-base dot grating GaAs cell.

CELL MODELING

As the basis of our P-base cell calculations we will use the high efficiency homojunction cell developed at the MIT Lincoln Laboratory (ref. 4). This cell has an unpassivated emitter surface and an AlGaAs heteroface back surface field layer. Using reasonable values for the various cell parameters (table I) along with a good value of the fill factor, one calculates an AMO efficiency for this cell of about 18 percent. The calculated performance parameters are given in table II along with the results of experimental measurements made on one such cell at this laboratory. In the table d, D, L, and N are the region thickness, diffusivity, diffusion length, and doping concentration, respectively, S is the surface/interface recombination velocity, and n_i is the intrinsic carrier concentration. As seen in the table, an optimized recombination velocity at the rear GaAs-AlGaAs interface was assumed to set an upper limit to the efficiency. This value, however, is not inconsistent with that found by photoluminescence decay techniques (ref. 5).

Also listed in table II are the performance parameters expected (ref. 1) if the emitter surface were passivated and the reflectivity were reduced through the use of a dual layer antireflection coating. As can be seen, a short circuit density of about 35 mA/cm^2 would result.

Let us now calculate the efficiency of a 1 percent junction coverage, P-base dot grating cell using the MIT cell parameters (table I) with the assumption that a passivating AlGaAs layer on all P surfaces enables achievement of the optimized planar cell J_{sc} level (35 mA/cm^2). In these calculations the emitter and base components of the dark saturation current were reduced from their planar cell values by factors of 100 and 10, respectively. The results, according to table II, indicate that efficiencies in the 24.5 percent range would be achievable.

GRATING CELL J_{sc}

Unfortunately, maintaining high current levels in a grating cell requires more than just passivating the cell surfaces. It has been shown that to

maintain full current capability in a stripe grating cell, the base diffusion length must be much larger than the distance between junction areas in the grating structure (ref. 2).

Since we do not have a similar analysis for the dot grating geometry, we must rely on measured results. An analysis (ref. 6) of the dot grating cell fabricated by Swanson et al. (ref. 7), indicates that this device, with a diffusion-length/grating-separation ratio of about 18, has an internal quantum efficiency close to 100 percent. It appears, therefore, that we can use that ratio as a lower limit for maintaining high current levels in the dot grating cell.

If we assume that photolithographic limitations put a lower limit of 1 μm on the diameter of the emitter dots, then the smallest grating spacing possible for a cell with a 1 percent junction coverage would be 10 μm. This, unfortunately, is about the same magnitude as the diffusion lengths measured in most GaAs solar cells. In order to make use of the potential of the grating geometry a means would have to be found to raise L by at least an order of magnitude.

One way to obtain long diffusion lengths would be to go to a higher resistivity base material in which L values approaching 500 μm have been measured (refs. 8 to 10). Figure 1 summarizes measured hole and electron diffusion length data as a function of doping concentration. The problem with going to lower doping levels to achieve increased current, however, is that one would expect (a priori) the base saturation current to rise precipitously, resulting in a serious decline in V_{oc}.

Yet, when one actually calculates the variation of efficiency with base doping level for the planar MIT cell it is found (fig. 2) that cell efficiency is surprisingly independent of base resistivity. In this plot J_{sc} and FF were assumed to be 29 mA/cm^2 and 0.86, respectively, while diffusion length data were taken from figure 1. We have plotted the efficiency-doping relationship for several values of the rear GaAs-AlGaAs interface recombination velocity that bracket Nelson's measured 300 cm/sec (0.004 D/L) value (ref. 5).

The significance of figure 2 is that is shows that it should be possible to fabricate high efficiency GaAs solar cells with long (>200 μm) diffusion lengths. The fact that such a cell is possible indicates that we should be able to fabricate a high current, and thus a high efficiency, dot grating GaAs cell.

GRATING CELL CONTACTS

A few words should be said at this point concerning electrical contacts to the dot grating cell. Because of the large number of emitter dots that would be required, and because of the close spacing between them, the metallization making contact to the emitter areas on the front surface of the cell would probably shadow a significant portion of the cell front face. It thus appears that we would be forced to resort to an interdigitated back contact scheme such as that used by Swanson et al. (ref. 7). Thus type of contacting, while being technically more difficult to achieve, does have the advantage of completely eliminating all shadowing effects. Thus when we calculate the value of J_{sc} expected from a back contacted dot grating cell, we find that

current levels over 36 mA/cm^2 are possible since the only losses are due to reflectivity and window absorption.

RESULTS

Figure 3 shows the calculated efficiency of a 1 percent junction coverage, back contacted dot grating cell as a function of base doping from $N = 1\times10^{5}$ cm^{-3} ($L = 200$ µm) to $N = 1\times10^{14}$ cm^{-3} ($L = 500$ µm). When the AlGaAs-GaAs IRV = 0, an efficiency of 25.3 percent is seen for a doping concentration of 1×10^{15} cm^{-3}. A penalty of about 1 percentage point is paid if the IRV is as high as 800 cm/sec (0.01 D/L).

The above calculations were performed for a cell with a base width, w, of 2 µm. Since a change in w is expected to affect cell current and voltage in opposite directions, we should, by varying w, be able to observe an efficiency maximum at some optimum value of the base width. Figure 4 shows the variation of efficiency with w for the case where $N = 1\times10^{15}$ cm^{-3}. The efficiency is seen to be rather independent of base width for values above about 2 µm. When the IRV = 0, the efficiency peaks at about 25.5 percent at a base width of about 7 µm. For the higher value of the IRV a maximum of just over 25 percent occurs at a width of about 25 µm. Not only is the efficiency independent of the base width, it also becomes insensitive to the AlGaAs-GaAs IRV as the width is increased. As can be seen, high efficiency is maintained to thicknesses of 100 µm (ref. 11). This fact should facilitate the construction of this device since it would permit the use of thick cell fabrication techniques such as those employed by Swanson et al. (ref. 7) to be used.

Similar calculations performed for the N-base GaAs cell indicate that efficiencies comparable to those predicted for the P-base cell are achievable if the N surfaces can be sufficiently passivated.

SUMMARY

The results of the preceding analysis can be summarized as follows:

1. In the dot grating configuration, P-base cell efficiencies of 25.5 percent, AMO, are possible with minor advances in existing technology.

2. Contrary to what may at first be expected, the open circuit voltage of the P-base GaAs cell is essentially independent of base resistivity.

3. P-base dot grating cell efficiency has been found to be effectively independent of cell thickness for base widths above about 2 µm, and insensitive to the rear GaAs-AlGaAs interface recombination velocity for widths greater than 10 µm.

4. Similar results are predicted for the N-base cell if the N surfaces can be sufficiently passivated.

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TABLE I. - P-BASE CELL PARAMETERS: MIT CELL

Parameter	Base	Emitter
L (μm)	20	0.5
D (cm^2/sec)	121	3
d (μm)	2	0.07
N (cm^{-3})	10^{17}	5×10^{18}
S (cm/sec)	0	10^7
n_i (cm^{-3})	2×10^6	2×10^6

TABLE II. - CALCULATED AMO PERFORMANCE PARAMETERS: MIT CELL

	J_{sc} (mA/cm^2)	V_{oc} (V)	FF (percent)	Efficiency (percent)
Experimental data	28.7	1.036	79.0	17.3
Optimized fill factor	28.30	1.034	86.0	18.4
SRV optimized, DLAR	34.94	1.061	86.0	23.3
1 percent dot grating	(35.00)	1.118	86.0	24.5

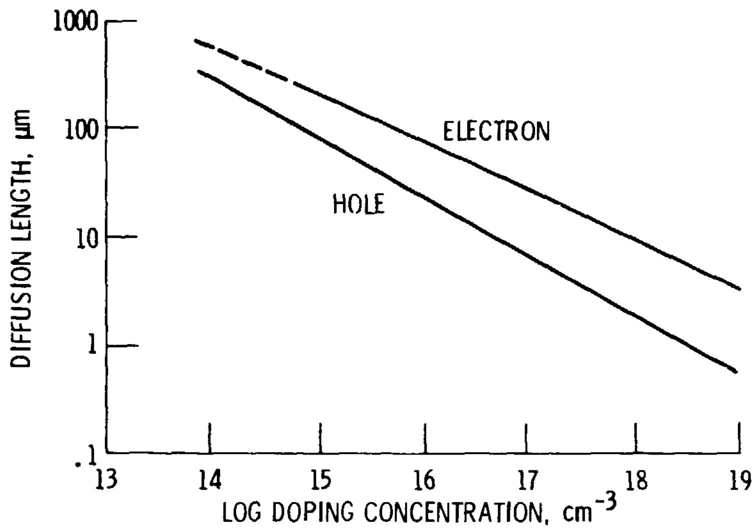

Figure 1. - Electron and hole diffusion lengths as a function of doping concentration.

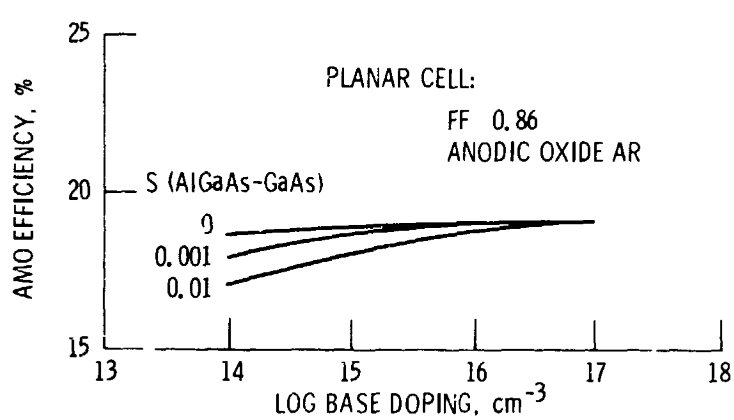

Figure 2. - Variation of P-base GaAs cell AMO efficiency with base doping level.

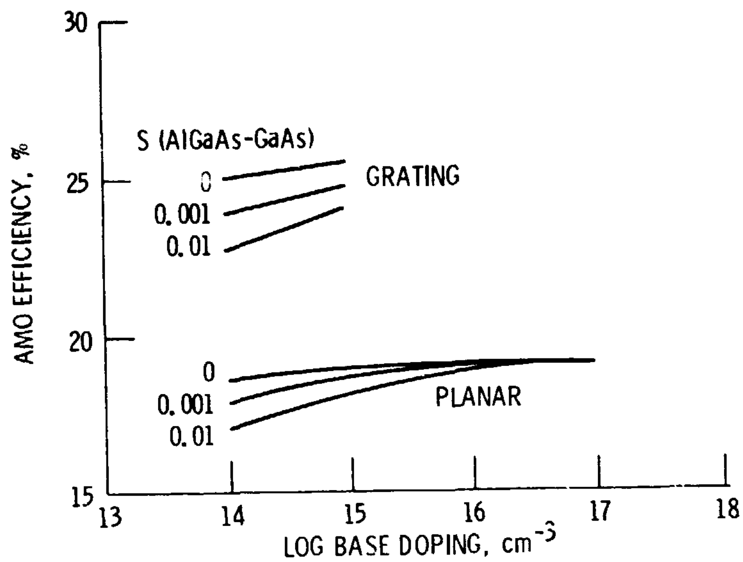

Figure 3. - Variation of P-base GaAs cell AMO efficiency with base doping level, planar vs 1% dot geometry.

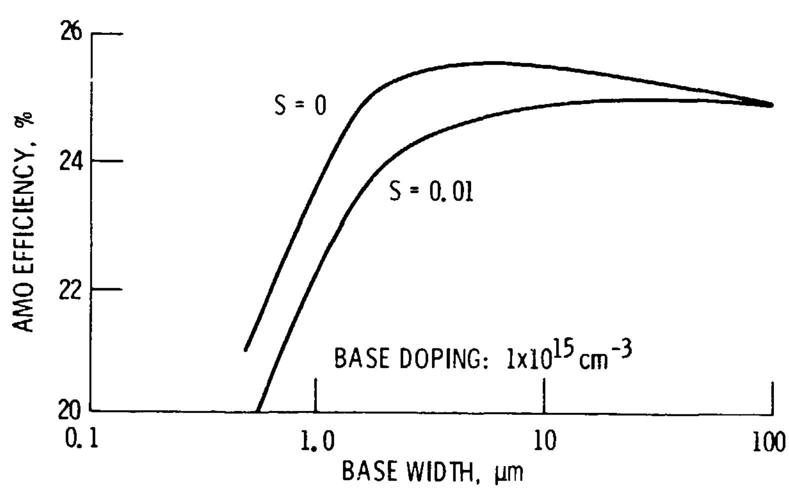

Figure 4. - Variation of P-base dot grating cell efficiency with base width.

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